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Subglacial Chemical Precipitates Record Antarctic Ice Sheet Response to Southern Ocean Warming

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Existing time-series of subglacial mineral precipitation beneath East Antarctica place calcite formation during time periods when Southern Ocean warming induces Antarctic ice acceleration and mass loss. The current geographic and temporal scope of this subglacial precipitate record is however limited, and it remains unclear whether ocean warming alone can account for their formation, or if additional environmental conditions contribute to an increased Antarctic ice response. Here we present an expanded precipitate archive that includes a continent-wide compilation of 41 new and previously reported calcite U-Th ages, paired with isotopic compositional data ($^{87}Sr/^{86}Sr$, ^{18}O, ^{13}C). In most cases, isotopic data characterize the calcite-forming waters as having experienced prolonged periods of rock-water contact (elevated $^{87}Sr/^{86}Sr$ and [$^{234}U/^{238}U$]) and originating from beneath the polar plateau (^{18}O <-50‰) prior to calcite precipitation beneath outlet glaciers on the ice sheet periphery. Thus, the U-Th ages and timing of formation record when interior meltwaters are exported to the sites of calcite sample formation at the ice sheet margins during periods of ice acceleration and thinning. Comparison between U-Th dates, which range from 16 to ~330 ka, and Antarctic ice core climate records confirms the coincidence between the acceleration of Antarctic ice and millennial-scale periods of Southern Ocean warming. Analyses of additional climate variables allow for the possibility that calcite formation and Antarctic ice acceleration tend to occur during the larger amplitude ocean warming events that cluster within periods of intermediate to high global ice volume, high obliquity and low precession. The sensitivity to global ice volume suggests a larger ice sheet is more reactive to Southern Ocean warming, while the orbital response we attribute to the reduction in Atlantic overturn and increased Southern Ocean warming that accompanies cooler Northern Hemisphere summers. Collectively these data illustrate how multiple factors work in concert to amplify the effect that ocean warming has on Antarctic ice loss.